High-Frequency Acoustic Propagation and Adaptive Signal Processing: An Integrated Research Program

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LONG-TERM GOALS

This research project fits within an overall reserach program with three long-term goals. These goals are to 1) quantify the impact of realistic environmental fluctuations in the ocean environment on the performance of adaptive underwater acoustic signal processing algorithms, 2) to develop adaptive underwater acoustic signal processing algorithms that are able to better exploit or compensate for environmental characteristics in realistic ocean environments, and 3) develop a better understanding of the impact of environmental fluctuations on the characteristics of the underwater acoustic propagtion channel.

OBJECTIVES

There are four specific scientific objectives to this research project. These are:

1) Develop analytical methods of quantifying the performance of adaptive least squares algorithms in randomly time-varying ocean environments. This is differentiated from prior work in this area in that the objective is to encompass a much broader range of channel fluctuations than can be handled by currently available techniques. More specificly, the objective is to develop techniques that can characterize algorithm performance in channels whose fluctuations can be described as arbitrary stationary stochastic processes with rational power spectra.

2) Develop least squares adaptive algorithms that exploit reduced channel dimensionality to improve performance in rapidly fluctuating enviroments and channel equalization algorithms that are better able to compensate for channel induced distortions in communications signals.

3) Develop adaptive algorithms that are based upon other than the traditional least squares criterion when appropriate to improve algorithm performance.

4) Develop an improved understanding of the impact of environmental fluctuations on the dimensionality of the fluctuations in the impulse response of the acoustic channel.

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APPROACH

The approach to developing analytic techniques for quantifying algorithm performance is based upon combining state-space system and matrix perturbation techniques to develop the equations necessary to quantify algorithm performance. The approach to algorithm development is to exploit the insights developed by the analytical characterizations of algorithm performance to identify potential avenues for improving algorithm performance and use linear algebra and function optimization formalisms to develop the desired algorithms. Finally, the approach to improving the understanding of the impact of environmental fluctuations on the channel impulse response is to combine propagation modeling with tightly focused field experiments to identify the relevent processes and characteristics and provide data from which statistical relationships can be developed.

WORK COMPLETED

Actual tasks completed this year include the following:

1) A state variable based equation for predicting the performance of least squares algorithms in the class of channels identified in objective 1) listed above has been developed and shown to provide better prediction capability than previously developed techniques.

2) A channel subspace filtering algorithm has been developed that can be used as a post-processor to traditional least squares channel estimation algorithms. The conbination of the least squares estimation algorithm and channel subspace post filter results in a significant improvement in performance when compared to the least squares estimation algorithm alone. This improvement in performance has been demonstrated on both simulated and experimental data

3) A new hardware system for conducting synchronized acoustic transmissions and receptions in the field has been designed for use in future acoustics experiments. The system exploits the recent development in the professional audio industry of inexpensive hard disk recording systems to achieve levels of performance at a cost at which they have not been achievable in the past.

RESULTS

The work completed as listed above and other continuing work has led to several interesting results. These include:

1) The state variable estimation error equation referred to in part 1) of the “Work Completed” section has led to several interesting results. These include an explicit expression describing the dependence of algorithm performance on the multi-dimensional temporal correlation function of the channel fluctuations. It also explicitly describes the subspace distribution of the estimation error and makes possible the direct calculation of the correlation matrix of the channel estimate and the cross correlation matrix between the channel and the channel estimate. The analytic expressions and insights which these calculations yield motivated and guided the development of the channel subspace filtering algorithm described in part 2) of the “Work Completed” section.

2) The state variable estimation error equation referred to in part 1) of the “Work Completed” section has also made possible the analytic calculation of the channel estimation error for channels whose intensity fluctuations can be described as the limiting cases of fully saturated and unsaturated channel.

These analytic results have been confirmed using simulations. The results show that the channel estimation error of a least squares algorithm is the same for channels having either class of fluctuations and the same second order statistics. The implication of this is that when using a traditional least squares channel estimation algorithm, the nature of the channel fluctuations (e.g., fully saturated or unsaturated) is of no use to the algorithm. By implication, this also demonstrates that algorithms other than traditional least squares algorithms will be needed to exploit prior knowledge of the nature of the channel fluctuations.

3) The channel subspace filtering algorithm developed as part of this work exploits two types of subspace characteristics of the channel fluctuations. Like previous algorithms, it is capable of exploiting reduced subspace structure. However, it is also capable of exploiting the unique dynamics of temporal channel fluctuations in each subspace and it is this capability that results in the majority of its performance improvement. This is a capability not available in prior algorithms. This algorithm is potentially useful in any applications that rely on the least squares identification of a dynamic system.

IMPACT/APPLICATIONS

All of the results above can impact least squares based adaptive signal processing algorithms by yielding improved performance in dynamic environments and by making possible prior predictions of algorithm performance.

TRANSITIONS

None

RELATED PROJECTS

This project is closely related to the surf zone acoustic communications work funded by the Ocean Engineering division. The work is closely coupled with the work conducted by Dr. Preisig under grant number N00014-99-1-0274 involving the analysis and modeling of the performance of acoustic communications systems in the surf zone environment. The work on the channel subspace filter was conducted primarily by Mr. Raj Nadakuditi as his Masters thesis work. Dr. Preisig is Mr. Nadakuditi's thesis advisor and Mr. Nadakuditi is supported by an ONR Special Research Award in Ocean Acoustics Graduate Fellowship.

PUBLICATIONS

T. Eggen, J. Preisig, A. Baggeroer, ``Communication over Doppler spread channels - Part II: Receiver Characterization and Practical Results", to appear in *IEEE Journal of Oceanic Engineering.*

J. Preisig, M. Johnson, ``Signal Detection for Communications in the Underwater Acoustic Environment", to appear in *IEEE Journal of Oceanic Engineering*.